Building Research Establishment Digest

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DIGEST 191

July 1976

Energy consumption and conservation in buildings

Buildings represent an important part of the UK energy economy. It is estimated that 40 to 50 per cent of the national consumption of primary energy takes place in building services, and that over half this energy is consumed in the domestic sector. By undertaking the technically feasible options it should be possible to achieve an ultimate saving of over 15 per cent of annual consumption of primary energy by measures in building services which would not impair environmental standards. Even undertaking only those measures which use well-established technologies and which are cost effective in the existing housing stock would save about six per cent of the annual UK consumption of primary energy.

Definition of terms

Gigajoule: The unit of energy used in this digest. It equals 10^9 joules and corresponds to about 278 kW hours or 9·5 therms.

Primary or gross energy: The (higher) calorific value of the raw fuel, eg oil, coal, natural gas, nuclear and hydro-electricity, which is input into the UK economy. Both nuclear and hydro-power are used only for the generation of electricity and the convention is adopted that the primary energy attributed to these inputs is equivalent to an efficient coal-burning power station producing the same electrical output.

Delivered or net energy: The energy content of the fuel actually received by the final consumer.

Energy overhead: The difference between the gross energy input to a particular fuel industry and the net energy delivered by that producer.

Useful energy: The energy required to perform a given task. The ratio of useful energy to net energy represents the efficiency of the device employed. The useful energy may not always be well defined particularly when the wasted energy of one process serves to reduce the useful demand of another, eg the fortuitous heat gain from the lighting in an office can reduce the demand for heat from the heating system.

Prepared at Building Research Station, Garston, Watford WD2 7JR
Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

Buildings in the national energy economy

The following discussion is based on 1972 figures to avoid any distortions from difficulties of supply in the period which immediately followed that year or the effect of price increases now being passed on to consumers. Primary energy consumption of the UK was $8{\cdot}9\times10^9$ GJ and energy delivered to final users was $6{\cdot}1\times10^9$ GJ, the difference representing losses in conversion and distribution by the fuel producers (Fig 1). The difference between the gross energy input and net energy output of the electricity industry is almost equal to that delivered to the whole of the industry sector. The relationship between the gross energy used and the net energy delivered for UK fuel industries is given in Table 1.

Table 1 Ratio of gross energy input to net energy delivered to users: UK fuel industries, 1972

Coal	1·03
Oil	1·09
Natural gas	1·07
Town gas	1·42
Electricity	3·82
Other manufactured fuels	1·38

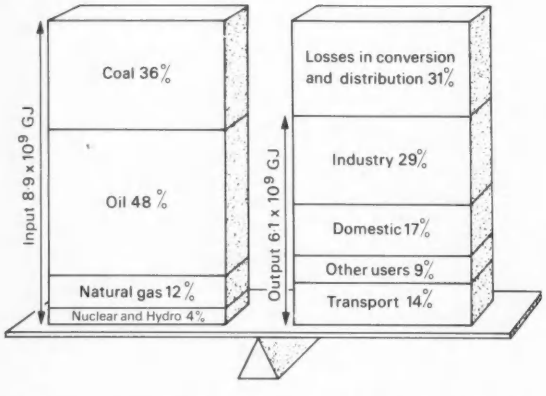

Fig 1 Gross energy input and net energy output of UK economy

It is important to bear in mind that the total amount of energy consumed to perform a particular task depends on the overall efficiency of converting primary energy to useful energy. For example, the high efficiency with which the electric motor converts delivered energy to useful mechanical energy more than recoups its losses in conversion when compared with, say, the internal combustion engine. Figure 2 is derived from Fig 1 by distributing the losses in conversion and distribution amongst the final users in proportion to their use of the various fuels in Table 1.

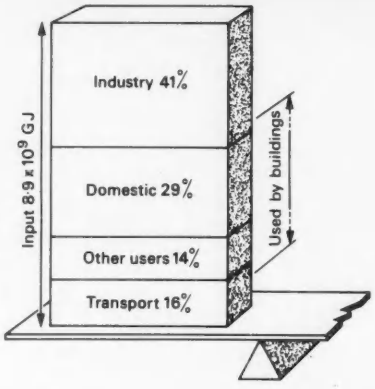

Fig 2 Gross energy used by final users

Nearly all the energy used by the domestic sector is used to provide heating and light within the building. This is also true of a large part of the energy used in the 'other users' sector since this sector also includes schools, hospitals and most offices. There will also be some energy used in the transport sector for building services (associated with railway and bus stations for example) and a good deal in the industry sector. Overall, at least 40 per cent and possibly 50 per cent of the national primary energy input can be associated with building services.

Energy use in the domestic sector

There were about 19 million domestic households in 1972, so the average net energy consumption in the home was about 81 GJ. This provided space heating, water heating, cooking, lighting and other sundry usages. Estimates based on field studies give the approximate usages shown in Table 2.

Table 2 Average annual domestic energy consumptions (GJ)

	Net	Gross	Useful (approx)
Space heating	52	74	30
Water heating	17	30	9
Cooking	7	16	5
Lighting, TV, etc	5	18	5
	81	138	49

An important feature of the UK domestic sector is the relatively large usage of electricity. It is about twice that *per capita* of the original six EEC member countries. Belgium and Holland provide particularly good examples as they share with the UK a maritime climate. The domestic sector *per capita* consumption of electricity in the UK is about $2\frac{1}{2}$ times that of Belgium and twice that of the Netherlands.

The Family Expenditure Survey carried out in 1972 can be used to estimate the consumption of fuel for groups of income in the range 0–£10 per week to greater than £80 per week. The result is shown in Fig 3. The average energy consumption obtained from the survey was 82 GJ, in good agreement with Table 2, derived from other sources. It can be seen

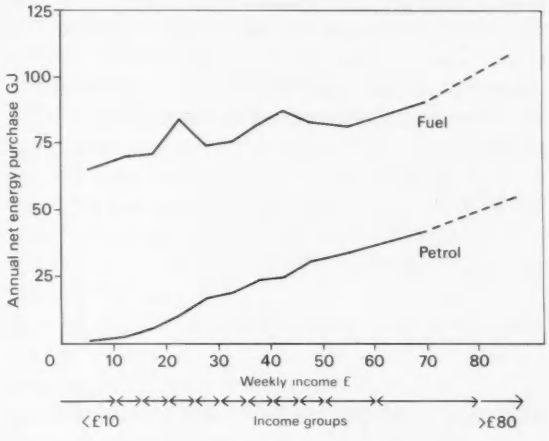

Fig 3 Estimated annual net energy purchases per household based on 1972 Family Expenditure Survey

that consumption rises fairly slowly with income. For an 8-fold increase in income, expenditure on domestic energy increases by only 74 per cent. This compares with an almost 20-fold increase in expenditure on petrol over the same income range. The small effect that income has on the consumption of domestic energy may possibly be attributed to a combination of partially cancelling factors. High income groups will probably have more modern, efficient appliances and better levels of thermal insulation, but there will also be a tendency towards higher comfort levels and larger heated zones. Patterns of occupation will also play a contributory role. Amongst the higher income groups of households there will be a larger fraction of dwellings which are unoccupied during working hours, probably in excess of 60 per cent at the median income group. This falls to as low as five per cent in the lowest income group which is made up predominantly of persons over 65 years of age.

In view of the differing social factors which affect energy consumption, it is not surprising that within any one socio-economic group in apparently identical housing, large differences in energy consumption are found. For example, a factor of five has been observed in a recent study of Scottish local authority housing between the lowest five per cent consumers and the top five per cent (Fig 4).

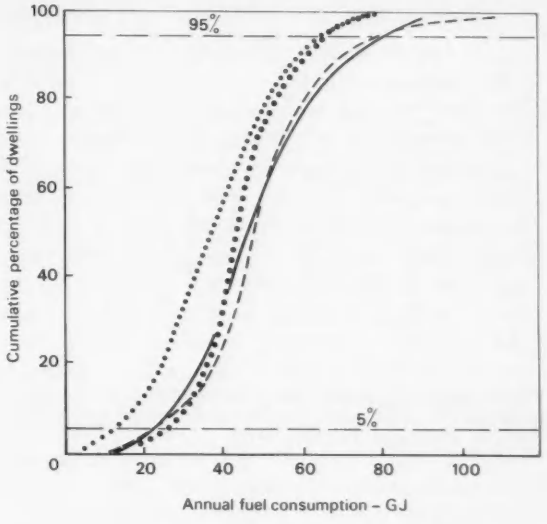

Fig 4 Distribution of annual fuel usage in four local authority housing estates of 100–200 houses. Average annual fuel consumption 42GJ

Variations also arise from differences in built-form, thermal insulation level and type of heating system. These last two factors are illustrated in Fig 5 which shows the total net energy consumption for over 1000 Scottish local authority dwellings monitored by BRE during 1972. When the consumption is corrected by the factors in Table 1 the gas systems have twice the primary energy efficiency of the electric systems. This difference is greater than that shown in the figure for dwellings with different levels of fabric heat loss but with the same type of heating system.

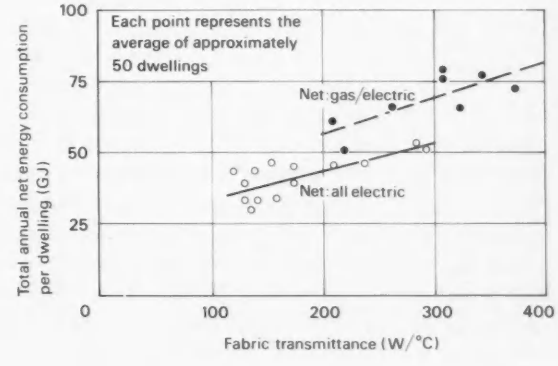

Fig 5 BRE (Scottish Laboratory) results. Total annual net energy consumption per dwelling for gas and electric space heating against fabric transmittance

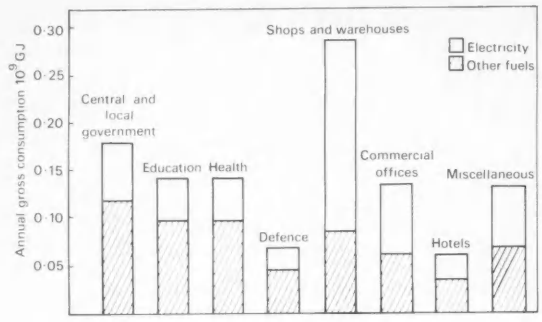

Fig 6 Estimated gross energy consumption in the categories public service and miscellaneous (derived from various tables in UK Energy Statistics 1973)

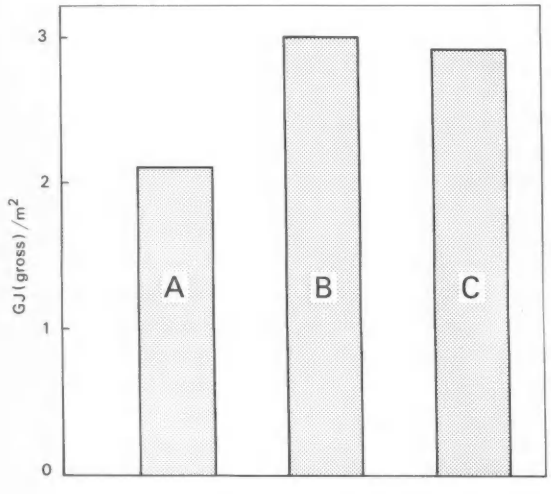

Fig 7 Primary energy consumptions for three built-forms of tall offices
A naturally-ventilated, naturally-lit, shallow plan
B air-conditioned, naturally-lit, shallow plan
C air-conditioned, artificially-lit at 750 lux, deep plan

Energy use in non-domestic buildings

There are considerable difficulties in using existing statistics to estimate energy use in non-domestic buildings. Figure 6 gives estimates of the division of the gross energy consumed by the 'Other users' sector against eight categories. The pattern of energy use varies widely between different building types, and from the pattern of use in the domestic sector, lighting plays a much more important role in the non-domestic sector. The lighting of offices and schools alone accounts for about one per cent of the national primary energy consumption. Lighting levels can represent a dominant heat source to an area and so incur a cooling load even in winter. Figure 7 illustrates the consequences for energy consumption where the gross energy consumption of a shallow, naturally-lit, naturally-ventilated office is compared with that of a deep-plan air-conditioned office lit by traditional fluorescent light fittings to a level of 750 lux.

The naturally-lit, naturally-ventilated office has a primary energy consumption almost one-third less than the air-conditioned, artificially-lit office. The use of more efficient fittings and particularly lighting standards optimised to the tasks to be performed can help to reduce the difference between the two built-forms.

Energy conservation economics

Most measures which conserve energy consume other scarce resources, with the possible exception of better husbandry. If the optimum use of all resources is to be made, resources devoted to energy conservation must be cost-effectively applied. In principle, this should be checked by comparing the stream of savings resulting from the measure with the rate of return on the same sum of capital placed in the next alternative investment. It is thus not unusual for the cost-effectiveness of an energy conserving measure to differ between consumers because of differences in alternative investment (or loan) opportunities and differences in the time horizons for decisions.

The principles of cost-effectiveness analysis for decisions in the public sector are well established. Both capital expenditure and cost savings are discounted at 10 per cent in real terms to their present value. The measure is cost-effective if the present value of the savings exceeds the present value of the capital costs. The present value of the savings is taken as that sum of money which, when invested at 10 per cent in real terms, would produce the same stream of savings through time. The present value of the capital costs is similarly defined. The present value can be conveniently computed from tables; a few useful values are given in Table 3.

Table 3 Present value of £1·00 p.a. for n years at 10 per cent discount rate

n	10	15	30	40	60	∞
pv (£)	6·15	7·61	9·43	9·78	9·97	10

Present value of £1·00 paid n years from now at 10 per cent discount rate

n	5	10	15	20	30
pv (£)	0·621	0·386	0·239	0·149	0·06

As far as possible all costs that are incurred during the measure's life, such as maintenance cost, should be included in the analysis. The future cost of energy is a source of considerable uncertainty, particularly when it is projected a considerable distance into the future. This element of uncertainty is largely removed if it is thought that the cost of energy is not likely to fall in real terms over the life time of the measure. Under these conditions, the best use of resources occurs if the measures are implemented as they become cost-effective with the fuel costs prevailing at that time.

The one important exception to this rule occurs when there is some first cost advantage in taking action now; for example, including a measure when the building is constructed. One possible way to meet this case is to test the sensitivity of the analysis to the use of several different assumptions concerning the variation of cost with time (examples are given in Ref 1).

The costs used in a public sector analysis should, strictly speaking, be the cost of the resources employed and should not include elements of tax or subsidy. However, current market prices can in most cases be taken as a good approximation. Many measures also offer a number of benefits (such as the reduced sound transmission through widely-spaced double glazing) but care should be taken in identifying the purpose of the analysis before they are included.

When undertaken by the consumer financing his own conservation measures, the analysis should use the prevailing prices, irrespective of any hidden tax or subsidy element. The consumer's own valuation of any additional benefits resulting from the measure should be included where possible. Many businesses have an internal discount rate as part of their management accounting procedure, so that a present value analysis can be undertaken along the same lines as discussed for the public sector. For the individual consumer the choice of a discount rate is more difficult. If, for example, he finances the measure as part of a mortgage, the mortgage rate would represent the correct discount rate after allowance for tax. The discount rate would be lower, however, if he used his savings. An important consideration for the individual consumer which might not appear in a public sector analysis is a limit on the time in which costs could be recovered. Thus, if the house market is relatively insensitive to the value of the particular measure the house-owner will wish to have recovered his capital (and lost interest) by the time his house is sold. Discussion of the consumer's point of view is given in Ref 1.

The conclusions of a cost-effective analysis can differ depending on whether the analysis is taken from the point of view of the nation, the firm or the consumer. Particular attention is to be paid to the choice of discount rate and to the costs and incidental benefits to be included in the analysis.

Options for energy conservation

In appraising the amount of energy saved by a given measure, it is important to allow for both the efficiency of the energy-consuming appliance and the energy overhead of the relevant fuel industry so that the total primary energy savings can be evaluated. Electricity, for example, has a consistently high efficiency at the point of use, but it is necessary to allow for the efficiency of electricity generation before it is possible to determine the overall efficiency of using an electric appliance compared with one which utilises the direct combustion of fossil fuel. An indication is given of the cost-effectiveness of the following measures as a means of conserving energy from a national point of view based on January 1975 resource costs. In general, a better indication of the use of resources will be obtained by determining the cost-effectiveness of each individual application. This is particularly true in the non-domestic sector where building types vary considerably.

Combined generation of heat and power

District heating schemes seldom offer substantial savings over individual fossil-fuelled appliances. They do, however, offer the opportunity for a combined generation of heat and electrical power. About 10 per cent of the national primary energy consumption could be saved if all buildings could be heated by such a scheme. There are substantial problems in matching the load factors of the heat demand and the electricity demand which can adversely affect both the energy efficiency and economics. One way in which this problem can be overcome is by utilising large-scale thermal storage to decouple the two demands for energy. The economics of such storage needs to be determined in each application.

Heat pumps

These use mechanical energy to transfer heat from a free heat source (commonly the outside air) to the building. It seems technically feasible to design heat pumps which would transfer three times as much heat as mechanical energy consumed. An electrical heat pump thus has a primary energy efficiency better than that of the best modern domestic boilers. The use of heat pumps to supply heat to buildings would save about seven per cent of the national primary energy consumption. Heat pumps at present available for domestic use are not economic at 1975 costs when compared with natural gas central heating systems, but there is considerable scope for cost reductions when the designs are optimised for UK conditions. Their economics would be most favourable in applications where electricity was the only energy source available.

Better primary energy efficiency

Electricity is a high-grade energy source in that it can provide motive power very efficiently even after allowing for power station losses. However, the demand for heating buildings is generally for low-grade heat and this can be provided with a better primary energy efficiency and usually more economically by the direct combustion of fossil fuels. It can be seen from Fig 5 that the net efficiency of gas relative to electricity is 70–80 per cent and the high primary energy efficiency of gas easily recoups this figure in primary energy terms. In primary energy terms, gas is about twice as efficient as electricity for space heating.

Further savings can be made in fossil-fuelled systems by improvement of control and husbandry and in avoiding oversizing at the design stage. Savings in the order of four per cent in the national consumption of primary energy can probably be made by improvements in primary energy efficiencies. The cost-effectiveness of different measures varies. In the domestic sector it would be cost-effective in most cases to replace existing electric space and water heating by direct fired fossil-fuelled appliances.

Thermal insulation

Possible options in the existing stock include roof insulation, cavity fill, double glazing, internal lining and external cladding. The full potential savings from insulation may not be realised, particularly in housing. This is because some consumers, especially those with a poor standard of heating, may take up some of the savings in higher comfort standards. An important additional contributory factor reducing the potential savings is the redistribution of internal temperature following improved insulation. The savings possible from improved thermal insulation amount to some four per cent of the national primary energy consumption.

In the domestic sector it would be cost-effective at January 1975 costs to undertake loft insulation and cavity fill where possible in the housing stock. The most advantageous implementations from a cost-effective point of view are in buildings heated continuously to a high standard, such as hospitals.

Ventilation control and heat recovery

Winter-time control of ventilation to the levels required for safety and comfort could save about one per cent of the national primary energy consumption. Further savings can be achieved by heat recovery from the exhausted air using a heat wheel, heat pump or other heat exchanging devices. Ultimate savings then rise to about two per cent of the national energy savings. The cost-effectiveness for dwellings at current costs remains to be established. This is particularly so in more recent constructions where the ventilation rates achieved in practice appear to be slightly below one air change per hour.

The most cost-advantageous applications of heat recovery are where the latent heat of water may also be recovered, such as in indoor swimming pools.

Natural energy sources

Solar gain already contributes to the heat input of a building during winter. In a more direct application of solar energy a solar collector may be used to supplement the domestic hot water supply, although a 6 m^2 collector can supply only about half the needs of an average dwelling and would not be cost-effective unless direct-fired fossil-fuelled heating was not available. The UK climate makes the generation of electricity from wind feasible although rotor diameters of the order of 10 m would be required in light wind areas if the major part of the dwelling heat load was to be met. Both solar and wind energy require either stand-by plant or extensive thermal storage. Geothermal energy represents another possible natural energy source and could supply heat to buildings through a district heating scheme if suitable areas could be found. It is estimated, after allowance for the restrictions placed by the existing building stock, that the use of natural sources of energy could save perhaps one to two per cent on the national primary energy consumption.

Lighting

Potential savings are limited to non-domestic buildings, particularly important areas being offices and schools. Savings from better lighting control, better lighting design to meet task requirements and choice of more efficient luminaires could save over one-half per cent of the national primary energy.

The cost-effectiveness of such measures is under investigation.

Many of the measures listed above interact or are mutually exclusive. After some allowance is made for this fact it may be concluded that in excess of 15 per cent of the national primary energy consumption could ultimately be saved by action in buildings. Not all the measures included in this figure represent a cost-effective use of resources at present costs, but in the domestic sector alone national savings of six per cent, which would be cost-effective when taken over the whole housing stock, can be obtained by improved thermal insulation and the direct use of fossil fuels instead of electricity for heating.

Future supply of energy to buildings

Figure 8 shows the projection of the primary energy consumption of the UK given in evidence to the Select Committee on Science and Technology in 1975, implied by an economic growth rate in the range of 2·7 to 3·3 per cent per annum over the next 15 years. The mix of primary fuels into the UK economy varies considerably within the range of the projections. The underlying assumptions which produce this variability are described more fully in Ref 3. With the notable exception of nuclear power with its characteristically inflexible input because of its long lead time in construction, it is evident that the energy supply can alter considerably in a time-span fairly short compared with the lifetime of a building. This emphasises the need for the designer to avoid decisions which severely limit the building users future options. Keeping options open may not necessarily incur great expense. For example, space can be earmarked for possible storage of fossil fuels even if natural gas is intended to be used initially in a boiler installation. For similar reasons, special attention should be paid to the thermal insulation of those building elements which would later prove extremely expensive to up-grade.

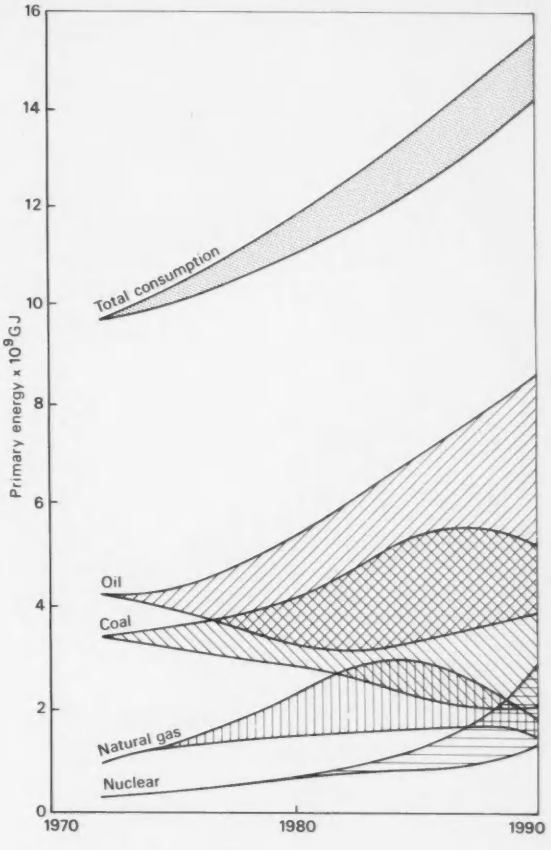

Fig 8 Envelopes of Department of Energy consumption forecasts (1974). The figure shows the range of primary energy inputs under a number of different assumptions for an economic growth rate of between 2·7 per cent and 3·3 per cent per annum

References

1 Energy conservation: a study of energy consumption in buildings and possible means of saving energy in housing. BRE Current Paper CP 56/75
2 Digest of UK Energy Statistics 1974, HMSO
3 Select Committee for Science and Technology (Energy Resources Sub-Committee) Evidence to Session 12 March Annex C

Corrections to Digest 108 *(1975 edition)*
Standard U-values

Page 3, Table 7

delete	Fibreboard	C	300	0·057
insert	Fibre insulating board	C	260	0·050

k-value for commercial copper should read: 200
and for pvc flooring should read: 0·40

add the following footnote to Table 7:

This table is extracted from Table A3.23 of the IHVE Guide 1970; some of the figures are representative values to be used in the absence of precise information. The values quoted for fibre insulating board are obtained from data produced since the publication of the Guide.

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